GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: December 16, 1977

Project Title: Collaborative Research in Tribology

Project No: E-25-681

Project Director: Dr. Ward O. Winer

Sponsor: National Science Foundation

Agreement Period: From 11/1/77 Until 4/30/79
(Grant Period -- Includes 6-month flexibility period)

Type Agreement: Grant No. ENG77-07976

Amount:
$45,000 NSF
7,030 GIT (E-25-342)
$52,030 TOTAL

Reports Required: Final Technical Report; Summary of Completed Project

Sponsor Contact Person (s):

Technical Matters

Dr. Clifford J. Astill, Director
Solid Mechanics Program
Engineering Mechanics Section
Division of Engineering
National Science Foundation
Washington, D. C. 20550
(202) 632-5787

Contractual Matters
(thru OCA)

Ms. Mary Frances O'Connell
Grants Manager
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Division of Grants and Contracts
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Washington, D. C. 20550
(202) 632-2858

Defense Priority Rating: N/A

Assigned to: Mechanical Engineering (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
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- Project Code (GTRI)
- Other ______

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: November 1, 1979

Project Title: Collaborative Research in Tribology

Project No: E-25-681

Project Director: Dr. Ward O. Winer

Sponsor: National Science Foundation

Effective Termination Date: 4/30/79

Clearance of Accounting Charges: 4/30/79

Grant/Contract Closeout Actions Remaining:

- _ Final Invoice and Closing Documents
- X Final Fiscal Report FCTR
- X Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________

TERMINATED

Assigned to: Mechanical Engineering (School/Laboratory)

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Project Code (GTRI)
Other ______________

CA-4 (1/79)

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

FINAL PROJECT REPORT

NSF FORM 98A

PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING

PART I—PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
School of Mechanical Engineering Georgia Institute of Technology Atlanta, Georgia 30332	Solid Mechanics	ENG 77-07976
	4. Award Period From 11-1-77 To 4-30-79	5. Cumulative Award Amount $45,000

6. Project Title
Collaborative Research in Tribology

PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

The objective of this research was to better understand the mechanics of highly stressed lubricated contacts such as occur in cams, gears and rolling element bearings. The kinematic, dynamic and thermal conditions occurring in these systems are extreme compared to most materials applications and the material responses are important to the operation of many machinery mechanisms. Two aspects of these systems were studied; 1) the surface temperature distribution resulting from energy dissipation in the shearing of the lubricant and surface asperity friction and 2) the shear rheological response of the lubricating material. The temperature studies were conducted by developing a technique of rapid infrared scanning of the surface radiation from the contact through one surface which was made of Al_2O_3. Local large temperature rises were observed to result from the dissipation process. These temperature rises are the controlling property which limits the severity of operation in tribological mechanisms Operating variable transients were found to have a major influence on surface temperatures and hence failure of the lubricating mechanism. The shear rheological studies were an extension of previous research where the lubricant was found to have a limiting shear stress which was successfully incorporated into a shear rheological constitutive equation. The research conducted on this grant covered the measurement of the relationship between dielectric transitions at elevated pressure and mechanical dilatometric transitions and pressure viscosity behavior. The various transitions could be related through an incorporation of the process frequency. The shear rheological model was also extended to a lubricant film thickness analysis which shows that for common lubricant and typical operating conditions the limiting shear stress property results in film thickness reductions of less than 40 percent compared to materials with no limit to the shear stress they can withstand. However for some materials with very low limiting shear stresses the film thickness reduction can be up to 90 percent.

The collaborative aspects of this program were with Professor H. S. Cheng of Northwestern University. Frequent discussion took place as well as the interchange of experimental data and modeling techniques. Professor Cheng was studying thermal scuffing and friction modeling in lubricated contacts using the limiting shear stress model.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM Check (√)	Approx. Date
a. Abstracts of Theses		X			
b. Publication Citations		X			
c. Data on Scientific Collaborators		X			
d. Information on Inventions	X				
e. Technical Description of Project and Results		X			
f. Other *(specify)*					

2. Principal Investigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
Ward O. Winer		1 August 1979

1a. ABSTRACTS

THERMAL EFFECTS IN TRACTION DRIVE ELEMENTS

Edvin Haakon Kool
Completed May 1979
M.S.M.E.

Committee: Ward O. Winer, Chairman
S. Ramalingam
John T. Berry

The traction between traction-drive elements is treated as an elastohydrodynamic (EHD) contact effect. In these rolling contacts energy is transmitted from one body to another through the shearing of the lubricant film. As with most energy transport processes there are losses. These losses appear as heat, which creates a temperature rise and will influence the traction behavior of the fluid film.

In order to make an experimental investigation of the temperature rise, an EHD contact simulator was built. By making one of the contact bodies out of sapphire, it is possible to observe the infrared radiation emitted by the opaque body. From this radiation, the surface temperature of the opaque body can be calculated.

The radiation was observed by an infrared camera unit that automatically scanned the region of interest.

Data was taken for rolling and sliding conditions in the Hertzian pressure range from 1.0 to 1.9 GPa and in the surface speed range from 0.5 to 1 m/sec.

1a. ABSTRACTS (continued)

ELASTOHYDRODYNAMIC INLET ZONE ANALYSIS FOR VISCOPLASTIC LUBRICANTS

Burak Gecim
Completed April 1979
M.S.M.E.

Committee: Ward O. Winer, Chairman
Prateen V. Desai
Melvin R. Corley

The visco-plastic portion of the constitutive equation proposed by Winer and Bair [1] is coupled with the equations of motion, and the governing equations are obtained from the conservation of mass principle. Isothermal, steady, incompressible conditions with negligible body and inertial forces are considered.

The "Grubin Type" film thickness analysis is performed for an EHD line contact configuration. The lubrication is assumed to be in the "fully-flooded", "full-film" regime.

The governing equations are solved for the pressure distribution in the inlet zone for a given set of operating conditions including the nominal film thickness h_o.

The objective of this study is to determine the effect of lubricant limiting shear stress in the inlet zone on the nominal film thickness.

There are two new concepts introduced to a classical "Grubin type" film thickness analysis; sliding speed and limiting shear stress.

Based on the data available [2] the limiting shear stress can be expressed as a linear function of pressure, at a constant temperature. Since in an EHD contact, pressure increases by orders of magnitude, so does the limiting shear stress.

Therefore, only under the severe operating conditions of extremely high sliding speeds or pressure gradients, does shear stress reach the limiting value. Under such circumstances a decrease of about 20 percent from Grubin's prediction of nominal film thickness is found. This decrement might be of importance if the film thickness is very small as a result of low viscosity, low rolling speed, or high load; then the rubbing of asperities will become much more likely.

Although the confirmation of the existence of a limiting shear stress is relatively new in the field of tribology, it is an intrinsic material property of the lubricants that have been used for many years. Therefore it is reasonable to conclude that, under usual operating conditions, with conventional lubricants, no drastic changes or sudden collapse in film thickness is expected. Hence the small (<30 percent) reduction in film thickness predicted in this analysis is reasonable.

1b. Publication Citations:

1. "A Review of Temperature Measurements in EHD Contacts", Proceedings of the Fifth Leeds-Lyon Symposium on Tribology, September 1978, The University of Leeds, England (W. O. Winer).

2. "Some Observations on the Relationship Between Lubricant Mechanical and Dielectric Transitions under Pressure", to be presented at the 1979 ASME-ASLE Lubrication Conference, Dayton, Ohio, October 1979 and accepted for publication in Trans. ASME, Journal of Lubrication Technology (S. Bair and W. O. Winer).

3. "Lubricant Limiting Shear Stress Effect on EHD Film Thickness", to be presented at the 1979 ASME-ASLE Lubrication Conference, Dayton, Ohio, October 1979 and accepted for publication in Trans. ASME, Journal of Lubrication Technology (B. Gecim and W. O. Winer).

4. "Simultaneous Temperature Mapping and Traction Measurements in EHD Contacts" to be presented at the 6th Leeds-Lyon Symposium on Tribology, September 1979, Lyon, France (manuscript in preparation and not attached).

1c. Scientific Collaborators:

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B. Gecim
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School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

H. S. Cheng
Professor
School of Mechanical Engineering
Northwestern University
Evanston, Illinois 60201
(was frequent collaborator in the research,
but not paid under this grant)

1e. Technical Description of the Project and Results

The actual grant funding (12 months at $45,000) was reduced from the original proposal request of (36 months at $139,000) hence the results appear to be small compared to the effort described in the proposal. Nevertheless, significant progress was made toward the understanding of two aspects of the behavior of highly loaded contact lubrication. These are the thermal characteristics of the system and the shear rheology of the lubricant.

The highly loaded contacts studied consist of a material subjected to rapid transient shear strain and pressure while passing between two high elastic modulus solid bodies. The energy dissipated per unit mass of material subjected to these conditions is large causing significant temperature transients and, for some materials, molecular degradation. These extreme conditions are found in many lubrication mechanisms such as gears, cams, and rolling element bearings but are seldom found elsewhere. The behavior of the solid-liquid system is relevant to mechanical system performance limitation and energy conservation because of energy dissipation in these mechanisms. The research performed on these systems consisted of the development of a continuous infrared radiation temperature mapping capability of the contact, and the further application of the limiting shear stress shear rheological constitutive model to the contact behavior.

The infrared temperature measurement technique in highly loaded contacts was pioneered by this group under previous NSF and NASA grants. In that work the technique for making the measurements was developed to give high spatial and time resolution at a spot in the contact. The scanning of the entire contact was done by moving the detector and was slow and tedious. The existence of high temperatures was clearly shown and found to be important. In the present research, an infrared scanning system was adapted to automatically scan the infrared radiation from the contact and surrounding region at the rate of 25 frames per second. An infrared scanner was available through the Architecture Department at Georgia Institute of Technology which was modified to scan a small region (10 x 12 mm) of which the contact was about ten percent. The ability to continuously monitor the field has led to a better understanding of the thermal behavior with particular reference to the transients. The quantitative data obtained proved the feasibility of the method. It has made available a powerful tool for further thermal studies in tribology which we expect to conduct. The technique is currently being utilized to study the thermal response of a standard friction and wear measuring system. We expect to further utilize the system for tribology studies.

The existence of a limiting shear stress and glass transition behavior of liquid lubricants under the high stress conditions of concentrated contact lubrication was confirmed through research in this laboratory under previous NSF and NASA grants. That work was extended under this grant. The extension consisted of study of the correlation between mechanical

1e. Technical Description (Continuation)

dilatometry and dielectric transitions under pressure, and their relationship with pressure viscosity and Brillouin light scattering transitions. It was found that if adequate account of process frequency is considered the dilatometry and dielectric transitions could be related for those materials with measurable dielectric properties. It was also shown that the pressure-temperature dependence of the transitions and viscosity were the same. A second effort along this direction was the application of the limiting shear stress shear rheological model to a Grubin-type elastohydrodynamic inlet analysis to predict film thickness. This analysis showed that for many fluids the limiting shear stress behavior has little effect on film thickness even though it frequently greatly influences the traction generated by shearing the material in the contact. The analysis has also shown that a very low limiting shear stress, which some fluids have, could explain the poor lubricating ability of these materials in highly stressed contacts.

In both the area of thermal and rheological behavior of highly loaded contacts significant progress has been made on this grant. Also in both areas techniques and understanding have been developed which should permit rapid advances which will be readily applicable.